UCRL- 100695
PREPRINT

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This paper was prepared for submittal to the
International Conference on Materials and Mechanisms of Superconductivity
Stanford University
Stanford, CA
July 23-28, 1989

July, 1989

Lawrence Livermore National Laboratory

SUPERCONDUCTIVITY AND MAGNETIC SCATTERING IN THE $Nd_{2-x}Ce_xCuO_{4-\delta}$ COMPOUNDS

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Samples of $Nd_{2-x}Ce_xCuO_{4-\delta}$ were prepared by annealing both in air and under vacuum. Electrical resistivity measurements showed that these materials in their normal state demonstrate a Kondo anomaly resulting from a combination of magnetic and phonon scatterings.

Recently, Tokura et al.[1] reported superconductivity in $R_{2-x}Ce_xCuO_{4-\delta}$, where R represents Pr, Nd, or Sm. Measurements of Hall and Seebeck coefficients[2] indicate that the majority charge carriers are electrons. These electrons are donated by a combination of Ce^{4+} ions and oxygen difficiencies.

Samples were prepared by solid state reaction from high purity Nd_2O_3, CeO_2, and CuO. Stoichiometric mixtures of the starting materials were heated in air at 950°C for 12 h. The resulting powders were reground and pressed into pellets at 1 kbar and fired in air at 1100°C for 12 h followed by quenching to room temperature. Both magnetization and resistivity measurements indicated that all of the samples quenched in air are not superconducting above 2K. In order to obtain superconductivity, it was necessary to anneal the sintered pellets in a reducing atmosphere. These samples were then annealed under vacuum at 875°C for 6 h, maintaining the pressure at 10^{-5} torr. Finally, the samples were furnace cooled to room temperature in two hours.

X-ray powder diffraction measurements indicated that both the air quenched and vacuum annealed samples are phase pure for $x \leq 0.20$. All the diffraction peaks were indexed by a tetragonal Nd_2CuO_4-type structure with crystal symmetry I4/mmm.

The experimental density of our ceramic samples is approximately 90% of the theoretical value of 7.25 g/cm^3. This is a rather high value considering the powder synthesis methods employed. This high density is of great importance in determining the intrinsic properties of the materials.

The dc electric resistivity $\rho(T)$ measurements were performed on rectangular specimens cut from sintered pellets employing the standard dc four-probe technique. To ensure good contacts between the electrical leads and the sample, four platinum wires were attached by silver epoxy on the sample surface, followed by annealing at 400°C in air for the air quenched samples and in a N_2 atmosphere for the vacuum annealed samples for half an hour to help the silver diffuse easily around the contacts on the sample surface. This process reduced the contact resistance dramatically.

We measured the dc electrical resistivity for both nonsuperconducting and superconducting $Nd_{2-x}Ce_xCuO_{4-\delta}$ samples $(0 < x \leq 0.2)$. All the samples annealed in air and those annealed under vacuum with $x < 0.17$ demonstrate a Kondo effect[3] resulting from the combination of magnetic scattering and phonon scattering.

In Fig. 1, the resistivity data of a superconductor $(x = 0.15)$ are shown in the temperature range 2-400K. Displayed in the inset of Fig. 1 is the field-cooled magnetization versus temperature in a field of 5 Oe. The normal state resistivity decreases with increasing temperature. We fit the normal state resistivity data by

$$\rho(T) = -23.42 \ln(T) + 0.017T + 155.65$$

where $\rho(T)$ is in units of mΩ cm. Other functional forms such as A/T^n, or $Ae^{b/T}$ do not fit the data.

For the air quenched samples, $\rho(T)$ also increases

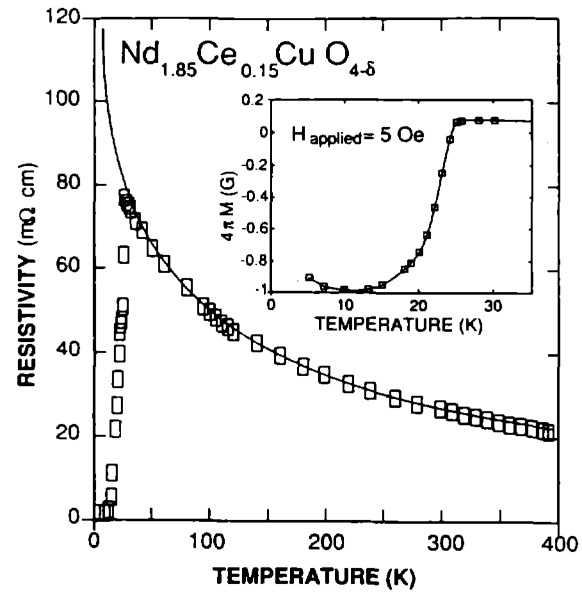

Figure 1. Resistivity of a superconducting $Nd_{1.85}Ce_{0.15}CuO_{4-\delta}$ sample as a function of temperature. The solid line represents a least-squares fits (see text). The inset shows the field-cooled magnetization.

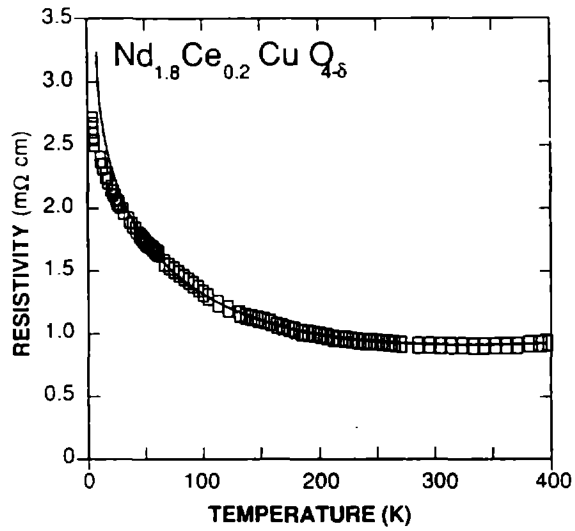

Figure 2. Temperature dependence of the resistivity for an air quenched $Nd_{1.8}Ce_{.2}CuO_{4-\delta}$ sample. The solid line represents a least-squares fit (see text).

monotonically with decreasing temperature. As an example, Fig. 2 shows the resistivity data of an air quenched sample with $x = 0.20$ in the temperature range 2-400 K. The solid line is a least-squares fit by

$$\rho(T) = -0.78\ln(T) + 0.0024T + 4.65$$

where the units of mΩ cm are used again for $\rho(T)$. There is a resistivity minimum at 325K.

The anomalous behavior of the temperature dependence of the electrical resistivity described above is normally associated with the Kondo effect. The $\ln(T)$ term comes from the magnetic interaction between the conduction electrons and the localized Nd^{3+} moments. The negative coefficient in the logarithmic term indicates that the interaction is antiferromagnetically coupled. The linear T term, on the other hand, is a result of the phonon contribution.

We note that in both Fig. 1 and Fig. 2, the solid lines above 55K going through each data point represent the quality of these fits. However, at about 55K, the actual resistivity data begin to deviate from these solid lines. Such deviation can be attributed to the effect of the crystal electric field. Magnetization measurements in the temperature range 2-400K indicate that all the $Nd_{2-x}Ce_xCuO_{4-\delta}$ materials exhibit susceptibilities typical of Nd^{3+} with a crystal field moment reduction below 55K.

In conclusion, both the superconducting and air quenched $Nd_{2-x}Ce_xCuO_{4-\delta}$ materials demonstrate a Kondo anomaly resulting from a combination of the magnetic and phonon scatterings.

Acknowledgements

Research at Davis and Livermore performed under the auspices of the U.S. Department of Energy for Lawrence Livermore National Laboratory under contract number W-7405-ENG-48.

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